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DUAL MICROSTRUCTURE HEAT TREATMENT OF A NICKEL-BASE DISK ALLOY

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Introduction. Gas turbine engines for future subsonic aircraft will probably have higher pressure ratios. This will require nickel-base disk alloys with temperature capability in excess of 1300°F. The AST Disk Progam was initiated to develop manufacturing technologies for advanced disk alloys. Under this program, Honeywell and Allison focused their attention on Alloy 10, a high strength nickel-based disk alloy, developed by Honeywell for application in regional gas turbine engines. Since tensile, creep, and fatigue are strongly influenced by grain size, the effect of heat treatment on grain size and the attendant properties were studied in detail (Ref. 1). It was observed that a fine grained material offered the best tensile and fatigue properties while a coarse grained material offered the best creep and crack growth properties. Therefore a disk with a dual microstructure, fine grain bore and coarse grain rim, should have a high potential for optimal performance.

A NASA funded disk program was initiated to assess the feasibility of producing a dual microstructure disk using Alloy 10. The objectives of this program were twofold. First, existing Dual Microstructure Heat Treatment (DMHT) technology would be applied and refined as necessary for Alloy 10 to yield the desired grain structure in full scale forgings for use in regional gas turbine engines. Second, key mechanical properties from the bore and rim of a DMHT Alloy 10 disk would be measured and compared to "traditional" subsolvus and supersolvus heat treatments to assess the benefits of DMHT technology. This paper describes the results of that property comparison. A previous report (Ref. 2) describes the DMHT process and resulting microstructure, however, for the reader's convenience the main points of that report are also summarized herein.

Material & Procedures. Alloy 10 powder of the composition shown in Table 1 was produced by argon atomization. The powder was then canned, HIPed, and extruded to billet. The billet was cut to mults and isoforged to "pancake" shapes 14" in diameter and 2" thick. These forgings were machined to the shape shown in Figure 1 for DMHT conversion.

The DMHT process, for Alloy 10, was designed and developed by Wyman-Gordon. It consists of a thermally insulated box that holds the bore of the disk but allows the rim to be exposed. The assembly is placed in a furnace at a temperature above the solvus. Prior to insertion into the furnace an air flow is begun. This air flow is maintained at a rate which keeps that portion of the disk inside the insulated box below the solvus. The temperature differential between the bore and rim produces a dual grain size in the disk as shown in Figure 2. The transition zone between the fine grain region and the coarse grain region in the DMHT disk occurs near the periphery of the thermally insulated box, about 3” from the center of the disk. Removal of the disk is a rather slow process which necessitated a subsolvus resolution step, at 2125°F/2Hr, followed by an oil quench and age at 1400°F/16Hr to obtain the high strength required for disk applications. Visual inspection of the disk revealed no evidence of quench cracking or other abnormalities after heat treatment.

The heat treated disk was then sectioned as shown in Figure 3 so that key mechanical properties could be measured. Tensile specimens were cut from the bore, transition region, and rim of the disk. Creep and crack growth specimens were cut from the bore and rim. Fatigue specimens were cut from the bore of the disk. Test temperature and other test parameters were identical to those used in previous studies on Alloy 10 (Ref. 3 and 4) so the DMHT test data could be compared with existing data for “traditional” heat treatments.

Results & Discussion. Since the DMHT disk was oil quenched after resolutioning, the DMHT test data will be compared with subsolvus, oil quenched data. However, as supersolvus oil quenching is generally not employed on Alloy 10 due to quench cracking concerns, the DMHT data will be compared to supersolvus, fan quenched data. For all three conditions, subsolvus, DMHT, and supersolvus, data comparison will be limited to material given a 1400°F/16Hr age.

As previously stated, a dual grain structure is produced by the DMHT process. The bore has a fine grain size, about ASTM 12, while the rim has a coarse grain size, about ASTM 6 to 7. Both grain sizes are typical of subsolvus and supersolvus heat treatments respectively. The transition region is located about 3” from the center of the disk and is remarkably symmetric. The morphology of γ' precipitates in the bore of the DMHT disk is similar to that observed in most subsolvus heat treatments. However, the rim of the DMHT disk contains a significant amount of relatively coarse γ', about 1 μm in diameter, which is not observed in most supersolvus heat treatments. A more detailed examination of DMHT microstructure can be found in Ref. 2.

Comparison of tensile properties can be found in Table 2 and Figure 4. At room temperature and 1300°F, the DMHT properties show bore data is equivalent to subsolvus data, while rim data is equivalent to supersolvus data. Further, the DMHT tensile properties through the transition region is intermediate in terms of strength and ductility, which indicates the grain size transition zone is not acting as a “weak link” in the disk. A key difference between DMHT and “traditional” heat treatments is seen in the strength gradient from bore to rim. For subsolvus or supersolvus heat treatments the strongest material is found at the rim of the disk due to cooling rate effects, however, with DMHT the reverse trend is observed, i.e. the bore is stronger than the rim. This is a direct result of the grain size gradient in the DMHT disk.

Creep times to 0.2% strain were measured at 1300°F/100KSI and 1500°F/50KSI in both the bore and rim of the DMHT disk. At 1300°F both bore and rim creep times were equivalent, running between 700 and 1000 hours. However, at 1500°F creep times of less than 5 hours were measured in the bore, while creep times approached 100 hours in the rim. Comparison of the DMHT creep data with subsolvus and supersolvus data is presented in Figure 5 using a Larson-Miller approach. As seen in this plot, coarse grain microstructures, DMHT rim or supersolvus, yield significant improvements at higher temperatures compared to fine grain microstructures, DMHT bore or subsolvus.

Minimum fatigue life of disks is often observed at intermediate temperatures, between 700 and 1000°F, and high stresses produced in the bore. For this reason, low cycle fatigue tests were run on DMHT bore specimens at 750°F. A strain controlled, 0.3Hz sinusoidal waveform with an R-ratio of 0.0 was employed in these tests (Ref. 3). The results of these tests are presented in Figure 6. Fatigue lives from subsolvus and supersolvus heat treatments are also plotted. As seen in this plot the fine grain microstructures, DMHT bore or subsolvus, have superior fatigue lives compared to the coarse grain, supersolvus microstructure. This trend is especially pronounced at 0.6%, an important design point for disk alloys.

The last property to be evaluated in this paper was crack growth. Kb bar crack growth tests were employed in this study using the same procedures outlined in Ref. 4. Cyclic crack growth tests were run at 750°F and 0.3Hz on DMHT bore specimens, while 90 second dwell crack growth tests were run at 1300°F on DMHT rim specimens. This choice reflects design limiting, crack growth criteria for modern disk applications. The cyclic crack growth results for the DMHT bore are plotted in Figure 7 along with data from subsolvus and supersolvus heat treatments. Very little difference in crack growth rates is observed for all three heat treatments. This is typical of crack growth data at temperatures below 1000°F, but it does show that DMHT technology does not adversely affect cyclic crack growth rates under these conditions. The dwell crack growth results for the DMHT rim are plotted in Figure 8 along with data from subsolvus and supersolvus heat treatments. Unlike cyclic crack growth, the dwell results at 1300°F show significant differences among heat treatments. While the DMHT rim crack growth rate is less than that for subsolvus material, it is significantly higher than that for the supersolvus material. It is felt that the slow cool after the DMHT conversion and/or the subsolvus resolution step may be responsible for the relatively rapid dwell crack growth rates in the rim of the DMHT disk. Both these factors would have a significant affect on γ' morphology and minimal impact on grain size. Recall the grain size of the DMHT rim is equivalent to that of supersolvus material, but their γ' morphologies exhibited significant differences. Additional research is planned to understand and hopefully remedy the shortfall of DMHT rim crack growth performance.

<u>Summary & Conclusions.</u> Existing DMHT technology was successfully applied to Alloy 10, a high strength, nickel-base disk alloy, to produce a disk with a fine grain bore and coarse grain rim. Specimens were extracted from the DMHT disk and tested in tension, creep, fatigue, and crack growth using conditions pertinent to disk applications. These data were then compared with data from "traditional" subsolvus and supersolvus heat treatments for Alloy 10.

The results showed the DMHT disk to have a high strength, fatigue resistant bore comparable to that of subsolvus Alloy 10. Further, creep resistance of the DMHT rim was comparable to that of supersolvus Alloy 10. Crack growth resistance in the DMHT rim, while better than that for subsolvus, was inferior to that of supersolvus Alloy 10. The slow cool at the end of the DMHT conversion and/or the subsolvus resolution step are thought to be responsible for degrading rim DMHT crack growth resistance.

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1. S. K. Jain, "High OPR Core Material (AoI 4.2.4), Regional Engine Disk Development", Final Report NAS3-27720, November 1999.
2. A. S. Watwe and H. F. Merrick, "Dual Microstructure Heat Treat Technology", Honeywell Report 21-11619A, May 2001.
3. J. Gayda, P. Kantzos and J. Telesman, "The Effect of Heat Treatment on the Fatigue Behavior of Alloy 10", NASA AST Report 32, February 2000.
4. J. Gayda, "High Temperature Fatigue Crack Growth Behavior of Alloy 10", NASA TM 210814, April 2001.

TABLE 1. COMPOSITION(W/O) OF ALLOY 10.											
Cr	Co	Mo	W	Al	Ti	Nb	Ta	C	B	Zr	Ni
10.2	15	2.8	6.2	3.7	3.8	1.9	0.9	0.03	0.03	0.1	BAL.

TABLE 2. COMPARISON OF TENSILE PROPERTIES.							
		75F				1300F	
	YIELD(KSI)	UTS(KSI)	ELONG(%)		YIELD(KSI)	UTS(KSI)	ELONG(%)
SUBSOLVUS	194	257	18		175	203	9
DMHT BORE	186	256	20		176	207	10
TRANSITION	176	245	17		162	203	11
DMHT RIM	163	231	19		154	198	10
SUPERSOLVUS	165	227	18		150	195	16

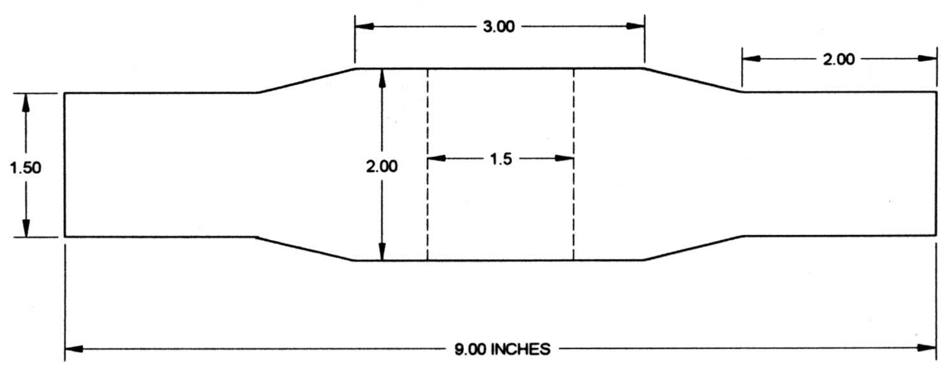

Figure 1.—DMHT disk shape.

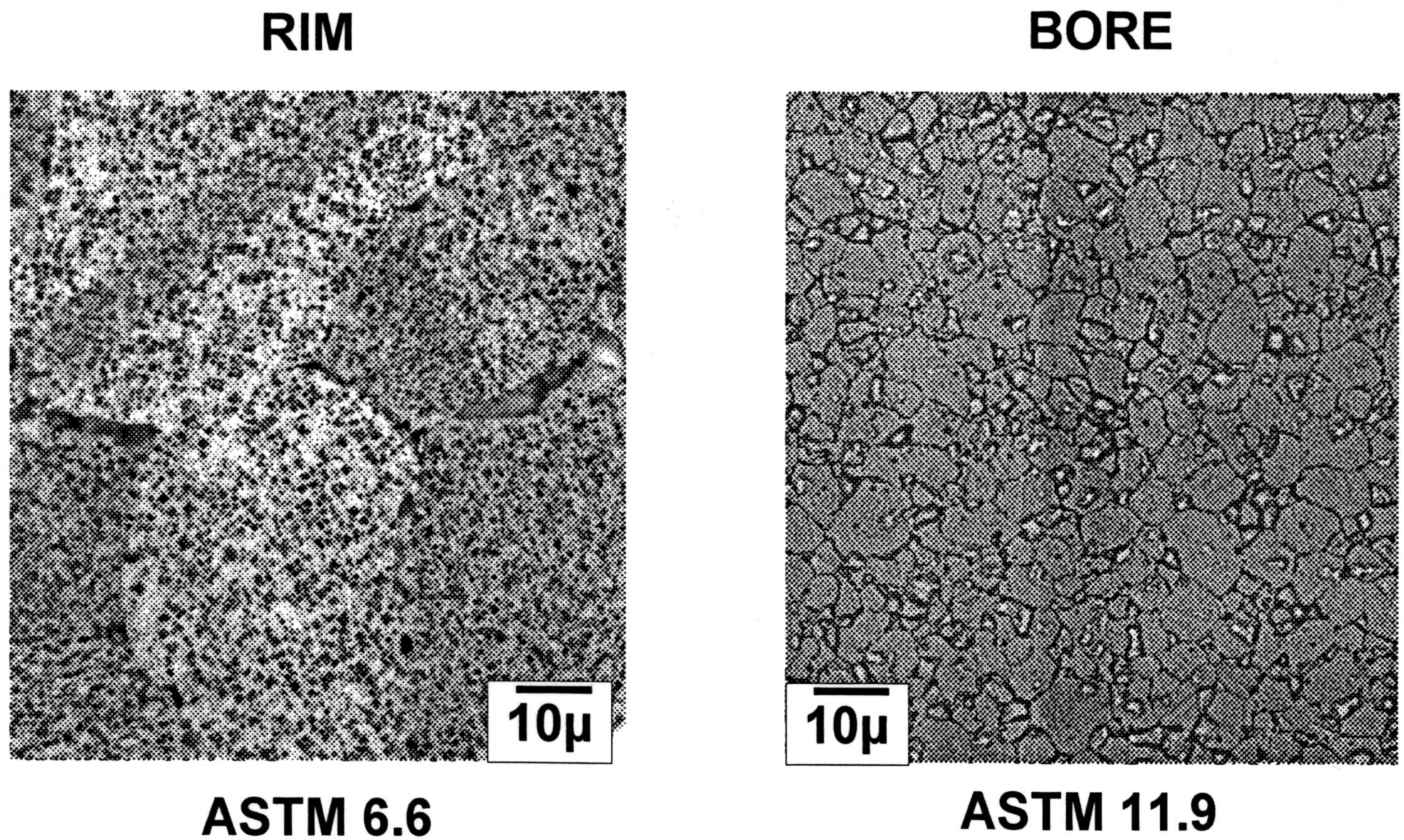

Figure 2.—Microstructure of DMHT disk.

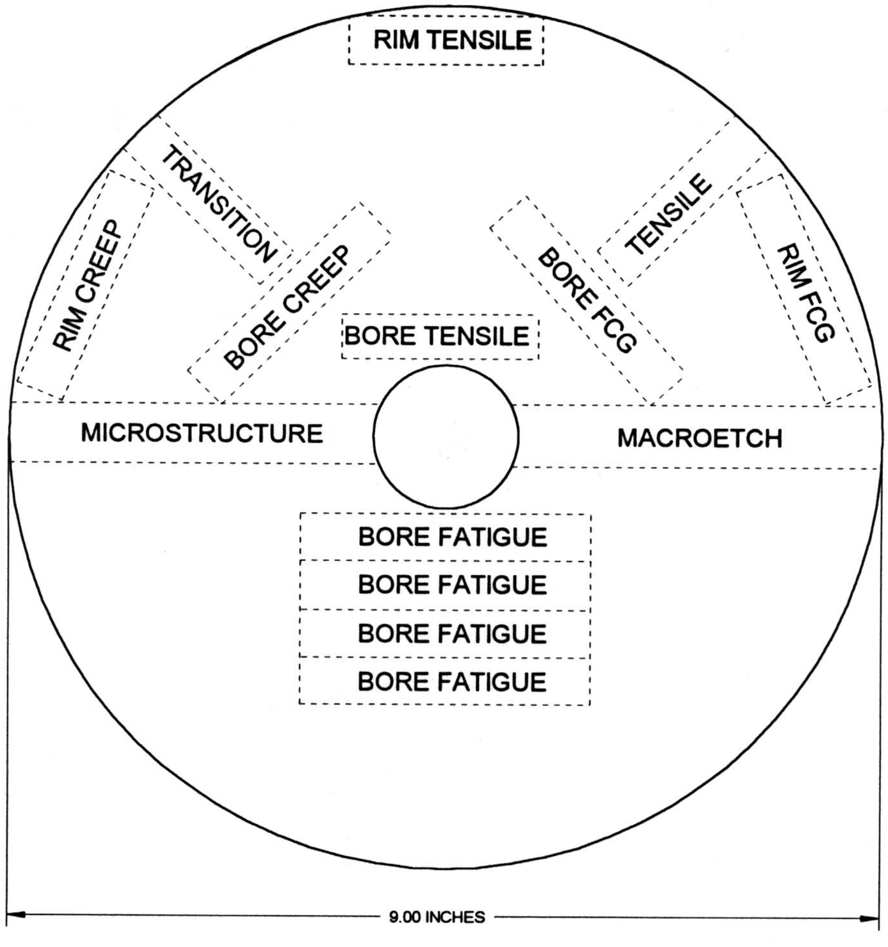

Figure 3.—DMHT cut-up plan.

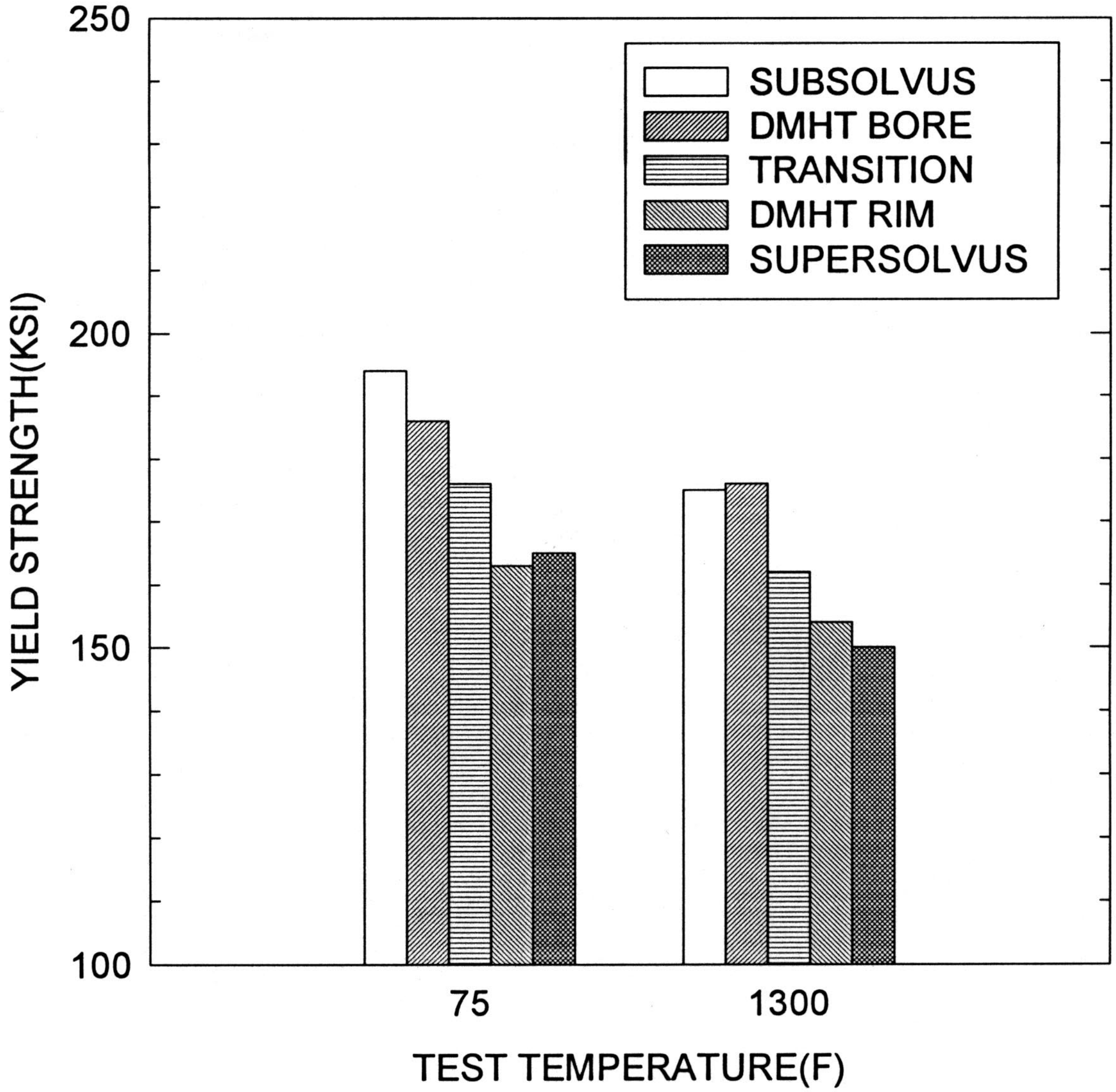

Figure 4.—Comparison of yield strength.

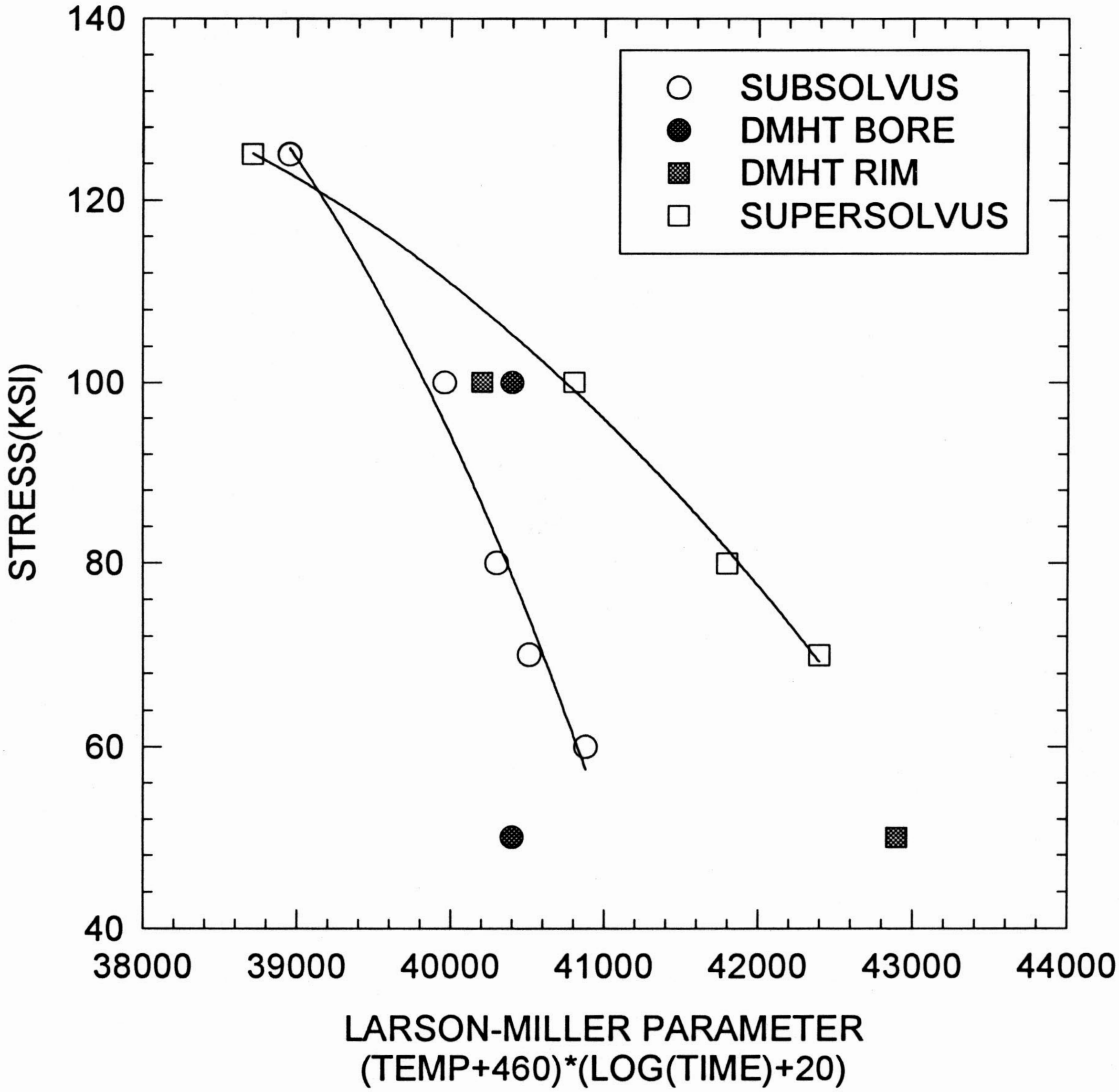

Figure 5.—Comparison of 0.2 percent creep life.

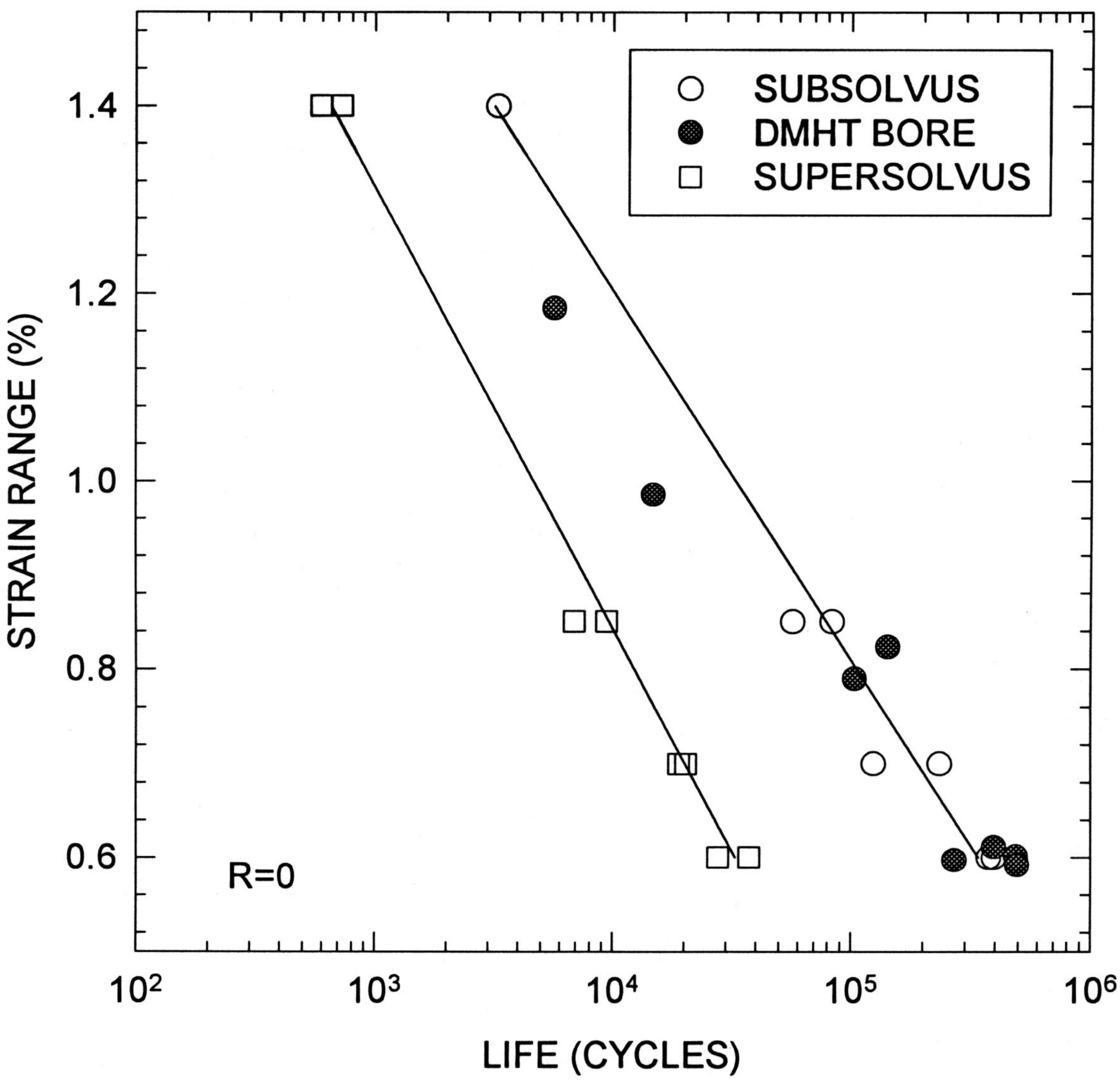

Figure 6.—Comparison of 750 °F fatigue life.

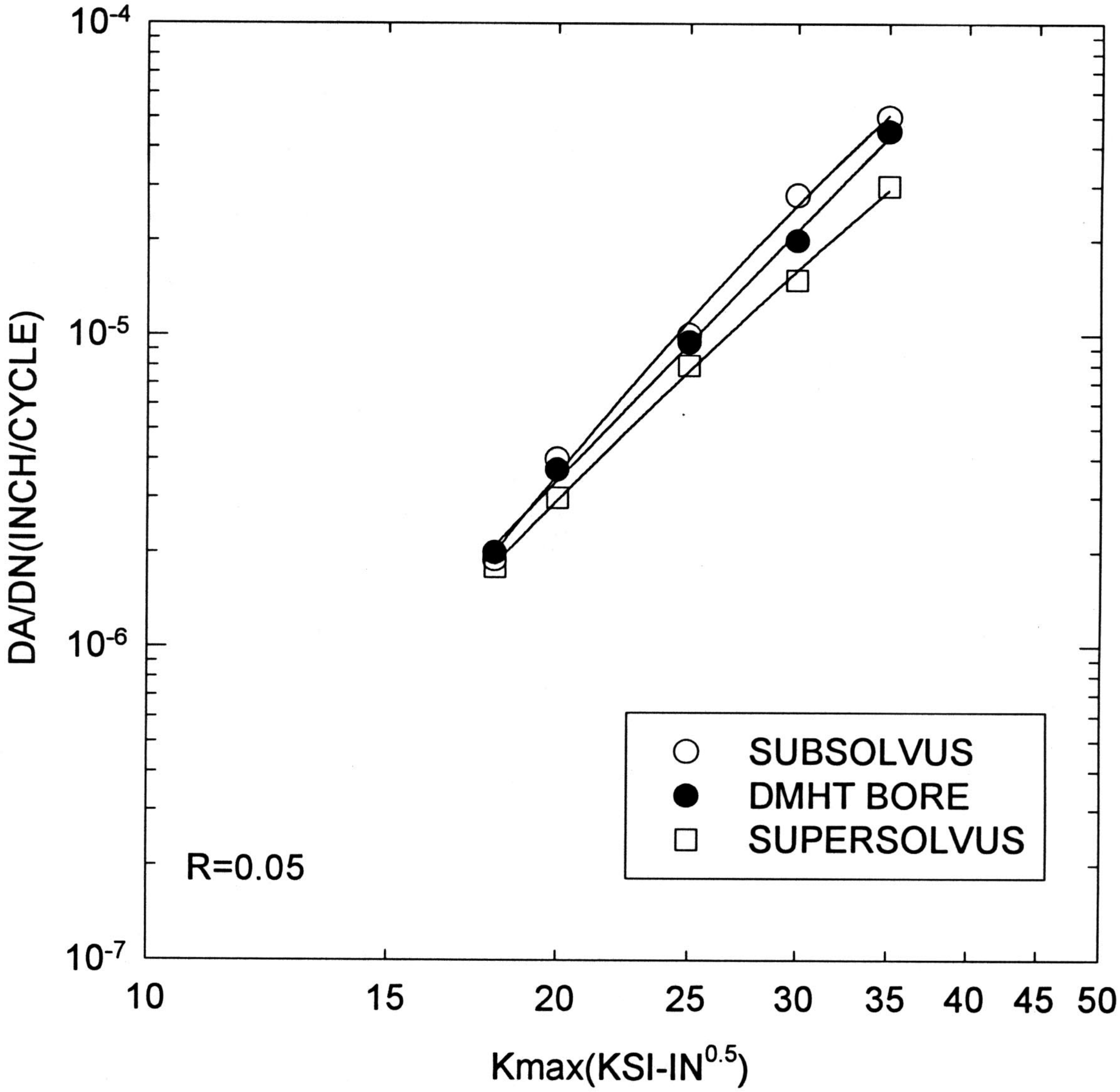

Figure 7.—Comparison of 750 °F cyclic crack growth rate.

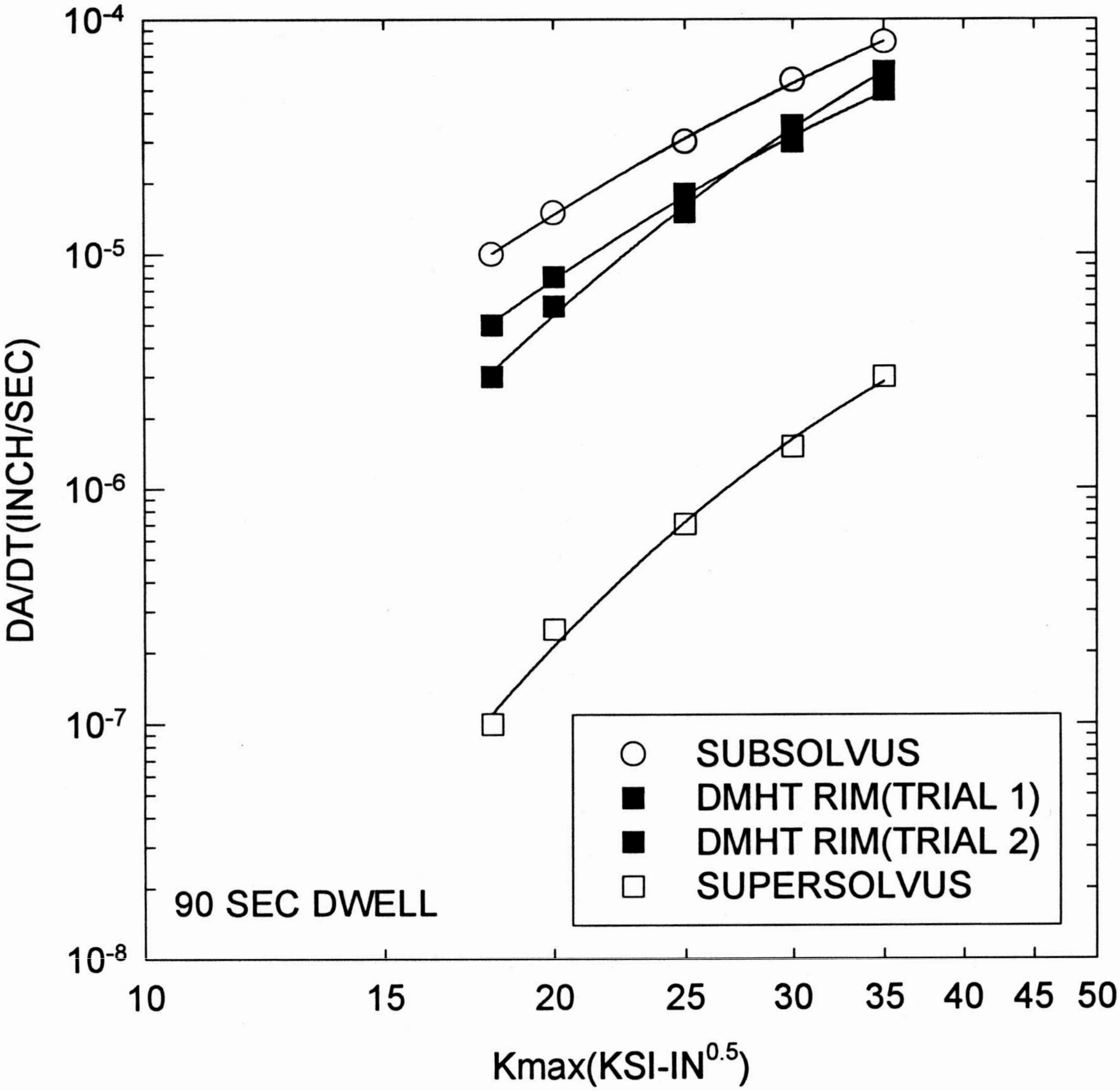

Figure 8.—Comparison of 1300 °F dwell crack growth rate.

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13. ABSTRACT ***(Maximum 200 words)***

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